

MAGNETIC RESONANCE IMAGING APPARATUS HAVING MOVING MAGNETS
CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority from U.S. Provisional Application No. 60/429,973, filed on November 29, 2002, and entitled "Magnetic Resonance Imaging Apparatus Having Moving Magnets," the disclosure of which is incorporated by reference herein in its entirety.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to magnetic resonance imaging apparatus and procedures. In magnetic resonance imaging, an object to be imaged as, for example, a body of a human subject is exposed to a strong, substantially constant static magnetic field. The static magnetic field causes the spin vectors of certain atomic nuclei within the body to randomly rotate or "precess" around an axis parallel to the direction of the static magnetic field. Radio frequency excitation energy is applied to the body, and this energy causes the precessing atomic nuclei to rotate or "precess" in phase and in an excited state. As the precessing atomic nuclei relax, weak radio frequency signals are emitted; such radio frequency signals are referred to herein as magnetic resonance signals.

[0003] Different tissues produce different signal characteristics. Furthermore, relaxation times are the dominant factor in determining signal strength. In addition, tissues having a high density of certain nuclei will produce stronger signals than tissues having a low density of such nuclei. Relatively small gradients in the magnetic field are superimposed on the static magnetic field at various times during the process so that magnetic resonance signals from different portions of the patient's body differ in phase and/or frequency. If the process is repeated numerous times using different combinations of gradients, the signals from the various repetitions together provide enough information to form a map of signal characteristics versus location within the body. Such a map can be reconstructed by conventional

techniques well known in the magnetic resonance imaging art, and can be displayed as a pictorial image of the tissues as known in the art.

[0004] The magnetic resonance imaging technique offers numerous advantages over other imaging techniques. MRI does not expose either the patient or medical personnel to X-rays and offers important safety advantages. Also, magnetic resonance imaging can obtain images of soft tissues and other features within the body which are not readily visualized using other imaging techniques. Accordingly, magnetic resonance imaging has been widely adopted in the medical and allied arts.

[0005] Several factors impose significant physical constraints in the positioning of patients and ancillary equipment in MRI imaging. Many MRI systems use solenoidal superconducting coils to provide a static magnetic field. The coils are arranged so that the patient is disposed within a small tube running through the center of the coils. The coil and tube typically extend along a horizontal axis, so that the long axis or head-to-toe axis of the patient's body must be in a horizontal position during the procedure. Moreover, equipment of this type provides a claustrophobic environment for the patient.

[0006] Iron core magnets have been built to provide a more open environment for the patient. These magnets typically have a ferromagnetic frame with a pair of ferromagnetic poles disposed one over the other along a vertical pole axis with a gap between them for receiving the patient. The frame includes ferromagnetic flux return members such as plates or columns which are located outside the patient-receiving area and extend vertically. A magnetic field is provided by permanent magnets or electromagnetic coils (superconductive or resistive) associated with the frame. A magnet of this type can be designed to provide a more open environment for the patient. However, it is still generally required for the patient to lie with his or her long axis horizontal.

[0007] Recently, ferromagnetic frame magnets having horizontal pole axes have been developed. As disclosed, for example, in commonly assigned United States Patent No. 6,414,490, the disclosure of which is incorporated by reference herein, and in copending, commonly assigned U.S. Patent Application Serial No. 09/718,946, filed on November 22, 2000, the disclosure of which is also incorporated by reference herein, a magnet having poles spaced apart from one another along a horizontal axis provides a horizontally oriented magnetic field within a patient-receiving gap between the poles. Such a magnet can be used with a patient positioning device including elevation and tilt mechanisms to provide extraordinary versatility in patient positioning. For example, where the patient positioning device includes a bed or similar device for supporting the patient in a supine or recumbent position, the bed can be tilted and/or elevated so as to image the patient in essentially any position between a fully standing position and a fully recumbent position, and can be elevated so that essentially any portion of the patient's anatomy is disposed within the gap in an optimum position for imaging. As further disclosed in the aforesaid applications, the patient positioning device may include additional elements such as a platform projecting from the bed to support the patient when the bed is tilted towards a standing orientation. Still other patient supporting devices can be used in place of a bed in a system of this type. Thus, magnets of this type provide extraordinary versatility in imaging.

[0008] FIG. 1 of the current application shows a sectional view of an MRI magnet subsystem 100. MRI magnet subsystem 100 includes a magnet having a ferromagnetic frame 102, a flux generating means 104 as is described in further detail below, and a patient handling system 106. The ferromagnetic frame 102 includes a first side wall 108 and a second side wall 110. The side walls 108 and 110 extend vertically. For purposes of clarity, FIG. 1 does not show the second side wall 110 or any

of its associated structures. The ferromagnetic frame 102 also includes a top flux return structure 112 and a bottom flux return structure 114. The top flux return structure 112 may include two columns 116 and 118. Between these two columns, a top opening 120 is defined. Similarly, the bottom flux return structure 114 may include two columns 122 and 124 that together define a bottom opening 126. Thus, the side walls 108 and 110 and the flux return members 112 and 114 form a rectilinear structure, with the top flux return structure 112 constituting the top wall of the rectilinear structure, the bottom flux return structure 114 constituting the bottom wall of the rectilinear structure and the side walls 108 and 110 forming the side walls of the rectilinear structure. The frame 102 of the rectilinear structure defines a front patient opening 128 on one side of the frame 102 and a similar back patient opening 130 on the opposite side of the frame 102. The ferromagnetic frame 102 further includes a first magnetic pole 132 and a second magnetic pole 134. The first magnetic pole 132 extends from the first side wall 108 towards the second side wall 110 and the second magnetic pole 134 extends from the second side wall 110 towards the first side wall 108. Magnetic poles 132 and 134 are generally cylindrical and are coaxial with one another on a common horizontal polar axis 136. Between the magnetic poles 132 and 134 is a gap 131, also referred to as the patient-receiving space, of the magnet. The gap or patient-receiving space 131 is accessed by the front patient opening 128, the back patient opening 130, the top opening 120 or the bottom opening 126.

[0009] The flux generating means 104 includes a first electromagnetic coil assembly 138 which surrounds the first magnetic pole 132, and a second electromagnetic coil assembly 140, which surrounds the second magnetic pole 134. These electromagnetic coil assemblies 138 and 140 may be either resistive or superconductive.

[0010] The patient handling system 106 is capable of three degrees or axes of motion. The patient handling system 106

may be termed a stand-up patient handling system, although the patient handling system 106 is not limited to standing position applications. The patient handling system 106 includes a carriage 142 mounted on rails 144. The carriage 142 may move linearly back and forth along the rails 144. The rails 144 typically do not block the bottom open space 126. A patient handling system operative in the manner described herein is disclosed in U.S. Application No. 09/918,369, filed on July 30, 2001, which is entitled "Positioning System For An MRI," the disclosure of which is incorporated by reference herein.

[0011] A generally horizontal pivot axis 146 is mounted on carriage 142. An elevator frame 148 is mounted to the pivot axis 146. The carriage 142 is operable to rotate the elevator frame 148 about the pivot axis 146. A patient support 150 is mounted on the elevator frame 148. The patient support 150 may be moved linearly along the elevator frame 148 by an actuator 152. Thus, a patient 154 can be positioned with a total of three degrees of freedom, or along three axes of movement or motion. Specifically, the patient handling system 106 can move a patient 154 in two linear directions and also rotate patient 154 around an axis. The solid black arrows of FIG. 1 show the three axes of movement possible with the patient handling system 106. Note that often the rails 108 are mounted such that portions of patient 154 may be positioned below the rails through bottom open space 126.

[0012] Often, a foot rest 156 may be used in order to support a patient in a standing position. Given the wide variety of positions possible with the patient handling system 108, many other such supports may be implemented, such as chair seats or straps.

[0013] The patient handling system 106 incorporates one or more actuators 103 and an actuation control unit 105. Actuators 103 may be conventional electrical, electromechanical, pneumatic, hydraulic or other devices capable of imparting the desired motion to the elements of the

patient handling system. For example, the actuators may include elements such as conventional stepper motors or other conventional electric motors linked to the elements of the patient handling system 106. The actuator control unit 105 may incorporate a conventional programmable controller, microprocessor, or computer with appropriate input and output interfaces. As further discussed below, the actuation control unit 105 is linked to a control computer and to the manual controls which regulate the patient handling system. The actuation control unit may be mounted in proximity to the actuators 103 as, for example, on carriage 142.

[0014] The MRI magnet subsystem 100 with patient handling system 106 can be contrasted with an older MRI system such as shown in FIG. 2A. Older MRI apparatus 200 has a magnet canopy 202 and a bed 204 on which the patient 206 lies recumbent. The bed 204 is typically capable only of linear motion to the left and right in the orientation of FIG. 2B. This linear motion is restricted to a horizontal plane. Thus, many of the advantages of the patient handling system as discussed in the aforementioned applications are unavailable. A control panel 208 with simple controls 210 may be mounted directly to the magnetic canopy 202. Alternatively, the control panel 208 may be mounted directly to the bed 204.

[0015] In addition to apparatuses for magnetic resonance imaging described above, U. S. Patent No. 5,008,624 issued to Yoshida on April 16, 1991 (the "Yoshida patent") and discloses a magnet having a pair of super conductor blocks one facing each other placed at two ends of a metallic U-shaped frame. Yoshida's magnet further includes a patient carrier in the form of a chair equipped with a lifting mechanism and a reclining mechanism. Yoshida further discloses that by rotating the U-Shaped frame to of the magnet or by lifting up and down the patient carrier with lifting mechanism, various relative orientations of the main magnet and the patient carrier are realizable.

SUMMARY

[0016] In accordance with an aspect of the present invention, an apparatus for magnetic resonance imaging is provided. The apparatus comprises a magnet having a gap for receiving a patient and means for moving the magnet in a substantially vertical direction so that a portion of a region of interest of a patient positioned within the gap can be imaged.

[0017] In accordance with this aspect of the present invention, the magnet preferably comprises a superconducting solenoidal magnet or may also preferably comprise a U-shaped magnet. It may also prove desirable if the magnet comprises a superconducting solenoidal magnet.

[0018] Further in accordance with this aspect of the present invention, the apparatus further desirably comprises a patient support positioned within the gap for supporting the patient.

[0019] Further in accordance with this aspect of the present invention, the means for moving the magnet preferably comprises one or more motors that are connected to one or more jacks for lowering or raising the magnet. Most preferably, the jacks are screw jacks. It is further desirable that the one or more motors comprise either electric motors, electromechanical devices, or pneumatic devices that are capable of imparting the desired motion to the magnet.

[0020] An additional aspect of the present invention is an apparatus for magnetic resonance imaging comprising a magnet having a patient receiving space and a pair of vertical support members connected to the magnet at opposite ends of the magnet. One or more motors are desirably coupled to at least one of the vertical support members so as to move the magnet in a substantially vertical direction.

[0021] In accordance with this aspect of the present invention, it is desirable that the magnet comprise a

solenoidal magnet. It may also prove desirable if the magnet comprises a superconducting solenoidal magnet.

[0022] Further in accordance with this aspect of the present invention, it is preferable that the one or more motors comprise at least one electrical device, or at least one electromechanical device, or at least one pneumatic device capable of imparting the desired motion to the vertical support member. It may also prove desirable if the one or more motors comprise at least one hydraulic device capable of imparting the desirable motion to the vertical support members.

[0023] In accordance with an additional aspect of the present invention, a method for magnetic resonance imaging is provided. The method comprises establishing a static magnetic field between a magnet gap and positioning a patient within a patient receiving space. The method further comprises positioning the static magnetic field so as to envelop a portion of the patient's anatomy and applying a gradient field to the static magnetic field so as to obtain a magnetic resonance image of the patient's anatomy.

[0024] Further in accordance with the method aspect of the present invention, positioning the static magnetic field comprises lowering the magnet so that the magnet gap envelops a portion of the patient's anatomy.

[0025] It may also prove desirable to position the patient on a patient support prior to placing the patient and the patient support in the patient receiving space.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] FIG. 1 is a diagrammatic sectional view of a MRI main subsystem with a stand-up patient handling system with certain portions removed for clarity of illustration;

[0027] FIGS. 2A and 2B are diagrammatic frontal and side elevation views of an older MRI apparatus;

[0028] FIG. 3 is a schematic of a front view of an MRI apparatus in accordance with an embodiment of the present invention; and

[0029] FIGS. 4 is a schematic of a front view of an MRI apparatus in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0030] FIG. 3 shows a schematic front view of a magnetic resonance imaging apparatus 300 in accordance with an aspect of the present invention. Magnetic resonance imaging apparatus 300 comprises a U-shaped magnet 302 that is movably mounted to a pair of screw jacks or shafts 306 by mounting sleeve 310. At one end of the screw jacks 306 is a support structure 312. At the other end of the screws jack 306 are motors 314.

[0031] Motors 314 may comprise electrical, electromechanical, pneumatic, hydraulic or other devices capable of imparting the desired motion to the screw jacks 306. In particular, the motor 314 causes the screw jacks 306 to rotate clockwise or counterclockwise to lower 318 or raise 320 the magnet 302 so that scanning may be performed of the region of the patient's anatomy of interest. The motor 314 itself may further include controls, not shown, that an operator may use to lower or raise the patient accordingly.

[0032] The magnet 302 further includes a pair of pole faces 325 and 327 that define a patient receiving space or gap 330. A patient support 333 may be positioned within the gap 330. Alternatively, a patient may stand within the gap 330 without the aid of a patient support. Preferably, prior to positioning a patient 336 within the gap 330, a static magnetic field is created across the pole faces 325 and 327 (in a horizontal direction). Most preferably, the static magnetic field is maintained even when a patient is not positioned in the gap. Alternatively, once the patient 336 is positioned within the gap 330, either by using the support 333

or by standing, the static magnet field may be created across the gap 330. Relatively small magnetic field gradients may then imposed on the static magnetic field to obtain images of the anatomical region of interest as described hereinabove. The patient support 336 preferably includes a step or foot support 337 for supporting the patient 336 in the standing position, however a seat may be provided for supporting the patient in a sitting position. Patient support 336 may also optionally include straps or other suitable restraints to restrict or control the movement of the patient during scanning.

[0033] In accordance with an aspect of the present invention, the motors 314 may be positioned far enough away from the magnetic field so as to avoid having to be shielded. Alternatively, the motors may be shielded to avoid being affected by the magnetic field.

[0034] In an exemplary operation, a patient 336 is positioned on the patient support 333. The magnet 302 is then suitably lowered or raised by activation of the motors 314. In particular, the motor 314 once activated causes the screw jack 306 to rotate which in turn causes the mounting sleeves to elevate or lower, depending on the direction of rotation, which in turn raises or lowers the magnet 302. In this way, various anatomical areas of interest of the patient 336 may be scanned, including the torso, head, ankles or feet of the patient 336.

[0035] FIG. 4 shows a schematic front view of a magnetic resonance imaging apparatus 400 in accordance with another aspect of the present invention. Magnetic resonance imaging apparatus 400 comprises a superconducting solenoidal magnet 402 that is movably mounted to a pair of screw jacks or shafts 406 by mounting sleeve 410. At one of the screw jacks 406 is a support structure 412. At the other end of the screws jack 406 are motors 414.

[0036] Motors 414 may comprise electrical, electromechanical, pneumatic, hydraulic or other devices capable of imparting the desired motion to the screw jacks. In particular, the motor 414 causes the screw jacks 306 to rotate clockwise or counterclockwise to raise or lower the magnet 402 so that scanning may be performed of the region of interest on the patient's anatomy. The motor itself may further include controls that an operator uses to lower or raise the patient accordingly. As previously discussed, the motors 414 may be shielded or placed outside the reach of the magnetic field to allow for reliable operation.

[0037] The magnet 402 comprises a tubular solenoid having an interior bore 425, the magnet being arranged to provide the required magnetic field in a working volume within the bore 425. A patient 436 can be positioned within the bore 425 so that the part of the patient's body to be imaged is disposed within the working volume. A patient support 433 capable of supporting the patient 436 may be also provided. Nonetheless, it is possible to have the patient stand without the aid of a patient support and perform the imaging procedure. However, to reduce patient movement and enhance throughput a support of some form, including a chair, is preferable. Where a support is used the interior bore 425 should be large enough to define a patient receiving space or gap 430 large enough to accept both the support 433 and the patient 436. The patient support 436 preferably includes a step 437 for supporting the patient 436 in the standing position, however, as previously noted, a seat may be provided for supporting the patient in a sitting position. Patient support 436 may also optionally include straps or other suitable restraints to restrict or control the movement of the patient during scanning.

[0038] Once a patient 436 is properly positioned within the patient gap 430 a static magnet field is caused to occur across the gap 430. Relatively small magnetic field gradients may then be imposed on the static magnetic field to obtain images of the anatomical region of interest as described

hereinabove. Preferably, the static magnetic field is always on to avoid having to re-energize the coils of the magnet each time a patient is to be scanned. Accordingly, the coils will preferably be energized at the start of the day and left on until the end of the day.

[0039] In an exemplary operation, a patient 436 is positioned on the patient support 433 while the magnet is raised 420 to a height that allows the patient to be initially positioned on the support 433. Once this initial positioning is complete the magnet 420 is then lowered so that the imaging surrounds that portion of the patient's anatomy of interest, as shown for example in FIG. 4. An operator may thereafter lower or raise the magnet 402 to better position the patient within the gap 430 as is needed. In particular, the motor 414 once activated will cause the screw jack 406 to rotate which in turn causes the mounting sleeves 410 to elevate or lower, depending on the direction of rotation, which in turn raises or lowers the magnet 402. In this way, various anatomical areas of interest of the patient 436 may be scanned, including the torso, head or ankles of the patient.

[0040] Although the invention herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present invention. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.